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DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

Technical Report 1730-TR

DEMOLITION OF CONCRETE LOCKS ON THE OHIO RIVER (RESEARCH PHASE)

Project 8F07-10-002

20 November 1962

U. S. Army
Engineer Research And
Development Laboratories

FORT BELVOIR, VIRGINIA

U. S. ARMY ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES
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The Commanding Officer
U. S. Army Engineer Research and Development Laboratories

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PREFACE

Authority for conducting this investigation is contained in Project 8F07-10-002, "Demolitions." A copy of the project card appears as the appendix to this report.

The research phase of the program was conducted from 8 July through 17 July 1961.

The Project Engineer for this program was Howard J. Vandersluis. He was assisted by James A. Dennis, Senior Explosives Technician, and by Eugene T. Chapman, Senior Photographic Technician. The tests were conducted under the general supervision of B. F. Rinehart, Chief, Demolitions Section.

These Laboratories acknowledge the cooperation of Col. Stephen Malevich, District Engineer, and personnel of the U. S. Army Engineer District, Huntington, West Virginia.

CONTENTS

Section	Title	Page
	PREFACE	iii
	SUMMARY	ix
I	INTRODUCTION	
	1. Subject	1
	2. Background and Previous Investigation	1
II	INVESTIGATION	
	3. Description	1
	4. General Test Procedures	2
	5. Tests of Concentrated Charges Fired on Concrete above Water	
	a. Procedure	3
	b. Results	5
	6. Opposed Charges Fired on Concrete above Water	
	a. Procedure	5
	b. Results	5
	7. Tests of Underwater Charges	
	a. Procedure	9
	b. Results	16
	8. Underwater Opposed Charges	
	a. Procedure	21
	b. Results	26
III	DISCUSSION	
	9. Examination of Methods of Testing	27
	10. Analyses of Test Results	28
	11. Evaluation of Tested Techniques	29
IV	CONCLUSIONS	
	12. Conclusions	30
	BIBLIOGRAPHY	31
	APPENDIX	33

ILLUSTRATIONS

Figure	Title	Page
1	Upper Guide Wall of Lock 30	3
2	Photographic Equipment for Recording Tests on Upper Guide Wall of Lock 29	4
3	Fifty-Pound Charge Placed on Face of Concrete Wall above Water Level	4
4	Crater Produced by 50-Pound Charge on Charge Side of Wall and Spall Produced on Side of Wall Opposite 50-Pound Charge	6
5	Crater 55 Inches by 53 Inches by 13 Inches Deep Produced by First Opposed Charge Test and Crater 71 Inches by 51 Inches by 17 Inches Deep Produced by Charge on Opposite Side	7
6	Crater 55 Inches by 51 Inches by $11\frac{1}{2}$ Inches Deep Produced in Second Opposed Charge Test and Crater 76 Inches by 42 Inches by 13 Inches Deep Produced by Charge on Opposite Side	8
7	Pole Charge Being Attached to Concrete Wall	9
8	Fabrication of Pole Charge from Conventional Explosive Blocks	10
9	Cross Section of Lower Guide Wall Showing Silt Deposit at Point of First 30-Pound Charge	11
10	Forty-Pound Charge Placed 7 Feet under Water at Point Where Silt Deposit Behind Wall Was 4 Feet from Water Surface Failed to Breach Wall	12
11	Forty-Pound Charge 5 Feet under Water Effectively Breached Wall	13
12	Forty-Pound Charge 7 Feet under Water Failed to Breach Wall	14
13	Cross Section of Upper Guide Wall Showing 40-Pound Charge Placed on Wall $2\frac{1}{2}$ Feet below Water Level	15

ILLUSTRATIONS (cont'd)

Figure	Title	Page
14	Forty-five-Pound Charge Placed $2\frac{1}{2}$ Feet below Surface on Shore Side of Wall Effectively Breached Wall	16
15	Upper Guide Wall of Lock 29 Showing Location of 35-Pound Charge Placed 4 Feet under Water	17
16	Detonation of 80-Pound Underwater Charge	19
17	Concrete Toppled Back into Water by 40-Pound Charge Placed 5 Feet under Water	19
18	Results of 30-Pound Charge Which Had Been Placed 5 Feet under Water	20
19	Remains of Wall Breached by 40-Pound Charge Placed 3 Feet 3 Inches under Water	20
20	Crater Produced by 50-Pound Charge Fired $2\frac{1}{2}$ Feet under Water and Spall Produced by Same Charge	22
21	Crater Produced by 45-Pound Charge Fired $2\frac{1}{2}$ Feet under Water and Spall Produced by Same Charge	23
22	Crater Produced by Two 40-Pound Charges Placed 4 Feet under Water, 26 Feet Apart, and Fired at Approximately Same Instant and Spall Produced by Same Two Charges	24
23	Two 20-Pound Pole Charges Prepared as Opposed Charges for Underwater Demolition	25
24	Underwater Opposed Charges Prepared for Simultaneous Detonation	25
25	Simultaneous Detonation of Two 20-Pound Opposed Charges Fired under Water	26

SUMMARY

This report covers tests of demolition techniques against massive nonreinforced concrete walls. Charges detonated on concrete above water were compared with similar charges detonated under water. An opposed charge technique was also tested. The tests conducted above water indicated that nonreinforced, low-quality concrete can be demolished with 30 percent less explosive (in a conventional package) than can reinforced, high-quality concrete. Underwater demolition required 30 percent less explosive than did demolition above water.

The report concludes:

a. Sixty pounds of Composition C-4 formed in a roughly square-shaped charge, 3 inches thick, is required to breach a nonreinforced concrete structure when the explosive is attached above the waterline, and 40 pounds, 3 inches thick, when the explosive is attached at a point 5 feet or more under water.

b. The opposed charge technique for demolition of concrete is not effective against long concrete structures.

c. Techniques for attaching explosive to massive concrete targets under water should be developed and tested.

d. Tests are required to establish optimum sizes and shapes of explosive charges for underwater demolition of massive concrete structures.

DEMOLITION OF CONCRETE LOCKS ON THE OHIO RIVER

(RESEARCH PHASE)

I. INTRODUCTION

1. Subject. This report covers tests of demolition techniques against massive nonreinforced concrete walls. Charges detonated on concrete above water were compared with similar charges detonated under water. An opposed charge technique was also tested.

2. Background and Previous Investigation. These Laboratories completed a test program in 1960 designed to develop improved methods for hasty demolition of concrete structures.[1] The program was confined to tests of external charges on concrete. All charges were fired on targets in the air (rather than under water or under the earth). Extensive underwater tests on concrete had been conducted by the Stanford Research Institute (SRI) in the early 1950's. These tests were restricted to demolition of small, beach-type obstacles such as tetrahedrons and concrete cubes. SRI had worked with sequentially detonated opposed charges and "bubble" charges.

Simultaneously, detonated opposed charges had been employed by Special Forces for demolition of small obstacles. Subsequently, their personnel had proposed that this technique be extended to demolition of long concrete piers and other structures.

The scope of the tests was limited by the inherent variability in the structures available. The 5-foot concrete walls varied in strength and method of construction. As an additional complication, the depth of the water behind the walls varied from point to point because of shifting river silt. The water level of the river changed from hour to hour during the tests. Also, just a little over a week was available for these tests. The walls were a part of a lock and dam system, and it was necessary to coordinate their destruction with a program for general removal of Ohio River obstacles.

II. INVESTIGATION

3. Description. When an explosive charge is placed against a concrete wall and detonated, the stress waves pass through the concrete wall. When these waves reach the opposite side of the wall,

1. H. J. Vandersluis, Hasty Demolition of Concrete Structures (Fort Belvoir, Virginia: USAERDL, 1961).

they generate tensile stresses which travel back into the wall toward the center. If, instead of air, there should be water or mud on the opposite side of the concrete, the shock waves would tend to pass on through this medium and the tensile reflection would be reduced. The tensile reflection is responsible for the most significant portion of the damage to the concrete, the spall. Reduction in this tensile reflection makes necessary a larger explosive charge to accomplish the same amount of demolition. If the charge is under water rather than in air, however, the water tends to confine the charge, increasing its effectiveness against the concrete. Theoretical considerations indicated that the loss of strength in the reflected tensile wave on the face of the wall opposite the charge would offset the increase in effectiveness caused by the confinement; consequently, the same amount of explosive would be required under water as is required above water to produce equivalent damage.

Accurate placement of charges on a target under water is difficult; hence, a secondary problem in the experimentation was finding a simple and effective method of attaching charges to the target under water so they would be in close contact with the target.

Finally, it was important that the opposed charge principle be tested. The tests accomplished by Special Forces had indicated that by employing such a technique, concrete could be breached with an amount of explosive equal in pounds to twice the thickness of the structure in feet. If the procedure were found to be effective against long concrete structures such as piers, the saving in explosive requirements would be huge. For example, instead of the previously specified 100 pounds of explosive required to breach a 5-foot pier, only 10 pounds of explosive would be necessary.

4. General Test Procedures. Test engineers planned to conduct most research tests on the 600-foot-long guide wall of Lock 30 on the Ohio River (Fig. 1). Portions of the lock were to be destroyed to clear the river for traffic after a new high-lift dam was completed at Greenup, Kentucky. Some walls were also available at Lock 29 near Ashland, Kentucky. Use of Lock 29 was restricted by proximity of some facilities of the city and by the amount of muck that had accumulated behind the walls. Also, the test team was under pressure to complete work because of the rigid time schedule for completion of the river clearance.

The planned approach was to establish the minimum explosive necessary to breach the nonreinforced 5-foot guide wall with a charge placed above the water level, and, with this information as a basis, test the opposed charge procedure above water. Next, tests were to be conducted to determine the minimum underwater charge

H7660

Fig. 1. Upper guide wall of Lock 30.

necessary to breach a 5-foot pier by conventional procedures. These would be followed by testing of underwater opposed charges.

The research phase of the tests was conducted under unfavorable weather conditions. Continuous rain made preparation and placement of charges difficult, limited the use of photography for instrumentation, and increased the nuisance effect of the blasts. These factors, together with the pressure of the tight schedule, reduced effectiveness of the tests.

Because of the limited time available, it was impracticable to instrument the walls prior to demolition. As a result, test engineers were dependent upon high-speed photography for instrumentation. Waddell cameras were used to photograph tests at rates up to 4,000 frames per second (Fig. 2).

5. <u>Tests of Concentrated Charges Fired on Concrete above Water.</u>

a. <u>Procedure</u>. A 50-pound charge was formed of Composition C-4 in a 20-inch by 20-inch square $3\frac{1}{4}$-inch thick. The inner layer of the charge consisted of blocks left in their plastic containers; the outer, $1\frac{1}{4}$ inches of explosive sliced from blocks from which the covers had been removed. The charge was bound together

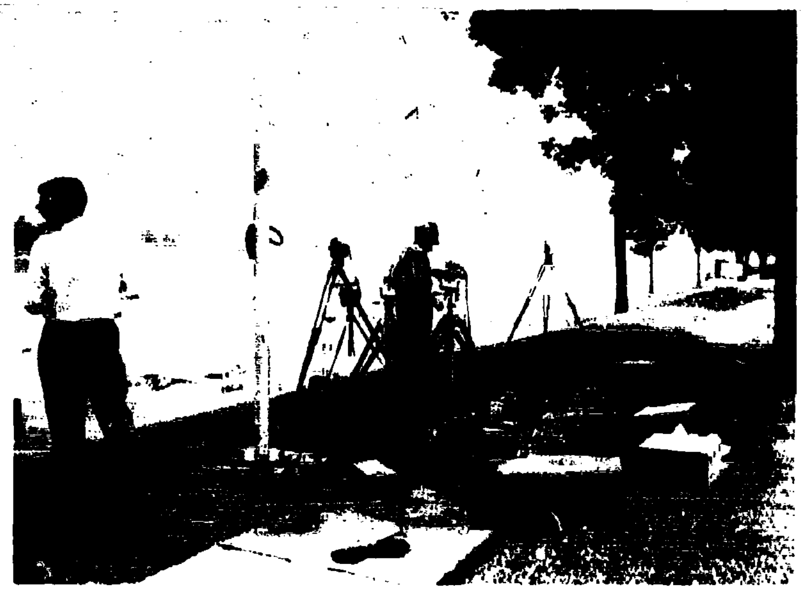

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Fig. 2. Photographic equipment for recording tests on upper guide wall of Lock 29.

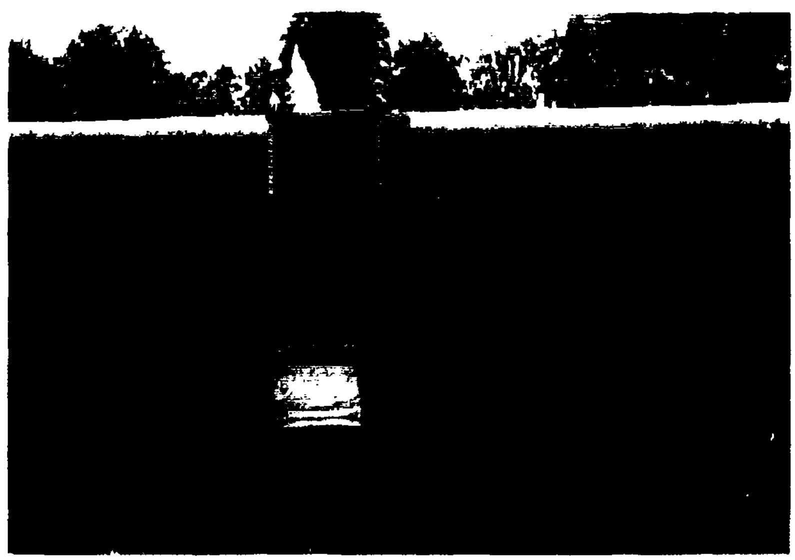

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Fig. 3. Fifty-pound charge placed on face of concrete wall above water level.

with masking tape. Testmen constructed a simple wooden platform to support the charge while it was being lowered into position on the wall. They attached a wire to studs imbedded on either side of the charge with a powder-actuated stud driver and stretched the wire across the charge to force it into close contact with the concrete. The platform was 2 inches above the waterline, and the center of the charge was about 4½ feet below the top of the wall. The charge was detonated by a blasting cap placed in the center about 1/2 inch into the explosive.

A second similar shot was formed, but this time the ends of the container were cut off. This procedure reduced the charge size to 17 inches by 18-1/4 inches by 3-1/8 inches thick, even though the weight remained 50 pounds (Fig. 3).

b. Results. The first 50-pound charge produced a clear breach of the wall. The crater was 82 inches wide and 55 inches high. The spall was 187 inches wide by 82 inches high (Fig. 4). The second 50-pound charge did not quite breach the wall. The crater was 20½ inches deep by 93½ inches wide by 59 inches high, and the spall was 26 inches deep by 166 inches wide by 61½ inches high.

6. Opposed Charges Fired on Concrete above Water.

a. Procedure. The formula proposed by Special Forces for breaching concrete piers was P = 2R, where P = total pounds of explosive required and R = the thickness of the pier. By this formula, explosive required for breaching the nonreinforced lock walls should have been 10 pounds. When the opposed charge technique was used, the explosive would be split, 5 pounds on one side of the wall and 5 pounds on the other. Instead of 10 pounds, 40 pounds (split 20 pounds on one side and 20 pounds on the other) was used in the first opposed charge test. The charges, 15 inches by 12¼ inches by 2-1/8 inches, were fastened to platforms directly opposite each other on the wall. Each charge was primed with nonelectric caps and detonating cord with the detonating cord tails measured and cut to exactly the same length. An electric cap was fastened between the two strands of detonating cord so that the detonating cord and, hence, the charges would be initiated at the same instant. When the first test failed to breach, it was repeated and the same procedures were used.

b. Results. Neither of the opposed charge tests breached the wall, even though four times the amount of explosive called for in the formula was used. In the first test, two craters were formed with an average width of 5 feet and depths of 13 inches and 17 inches, respectively (Fig. 5). After the second test, the crater widths were

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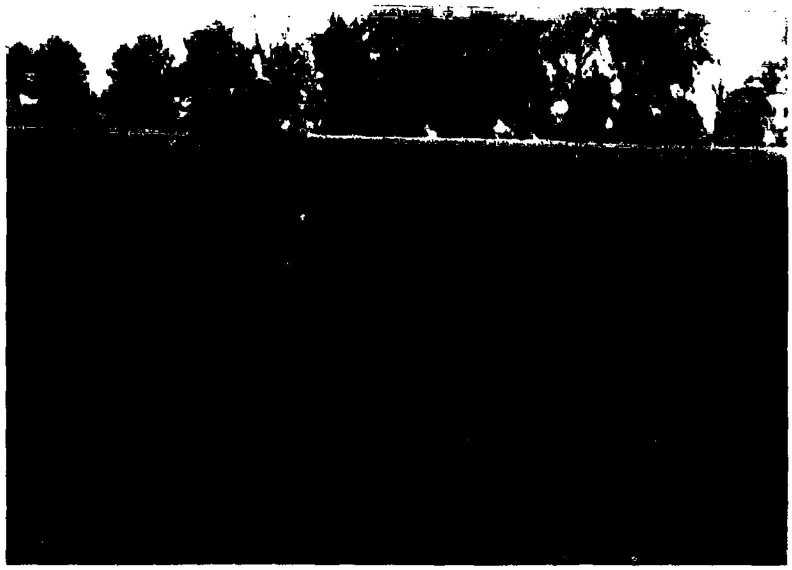
Fig. 4. Crater produced by 50-pound charge on charge side of wall (top) and spall produced on side of wall opposite 50-pound charge (bottom).



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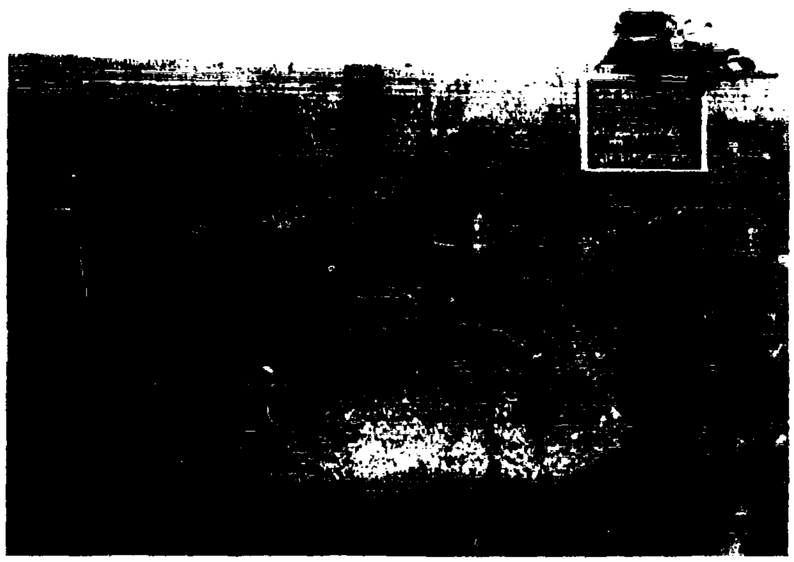

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Fig. 5. Crater 55 inches by 53 inches by 13 inches deep produced by first opposed charge test (top) and crater 71 inches by 51 inches by 17 inches deep produced by charge on opposite side (bottom).

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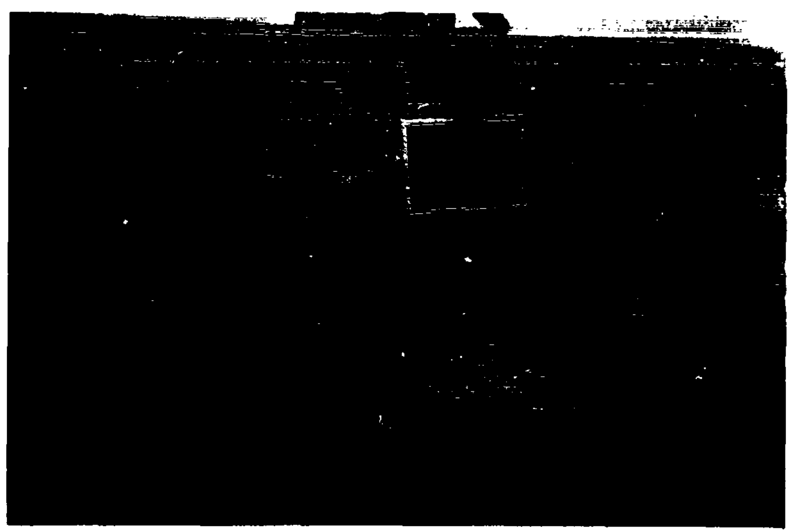

H7646

Fig. 6. Crater 55 inches by 51 inches by 11½ inches deep produced in second opposed charge test (top) and crater 76 inches by 42 inches by 13 inches deep produced by charge on opposite side (bottom).

found to be similar to those in the first test, and the depths were $11\frac{1}{2}$ inches and 13 inches, respectively (Fig. 6).

7. Tests of Underwater Charges.

a. Procedure. The first underwater charge weighed 80 pounds. The explosive was formed into a rectangle 20 inches by 22 inches by 3-1/8 inches and was attached to a wooden platform which, in turn, was attached to a 1- by 4-inch board handle. The charge was detonated 5 feet below the water level which, at that time, was 1 foot below the top of the concrete. (These tests were conducted on the lower guide wall of Lock 30. The previous tests were conducted on the upper guide wall where the water level was considerably lower.) A testman in the water next to the wall drove two studs into the wall just above water level, using the powder-actuated stud driver. He then centered the charge handle between the two studs, stretched a wire across it, and fastened the wire to the studs. The testman on the wall placed a small block between the handle and the wall in order to wedge the handle against the fulcrum formed by the wire; thus he forced the charge against the wall. The charge was primed with a cap placed into the explosive through a hole in the platform (Fig. 7).

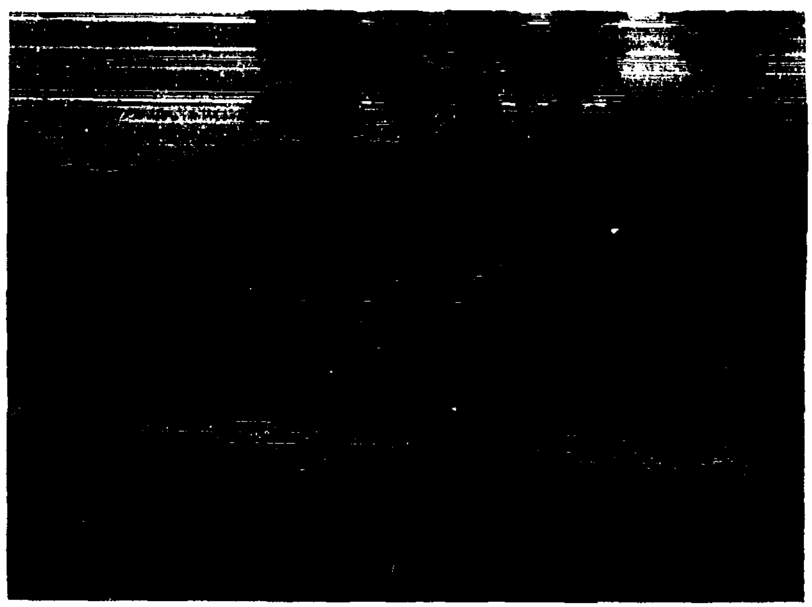

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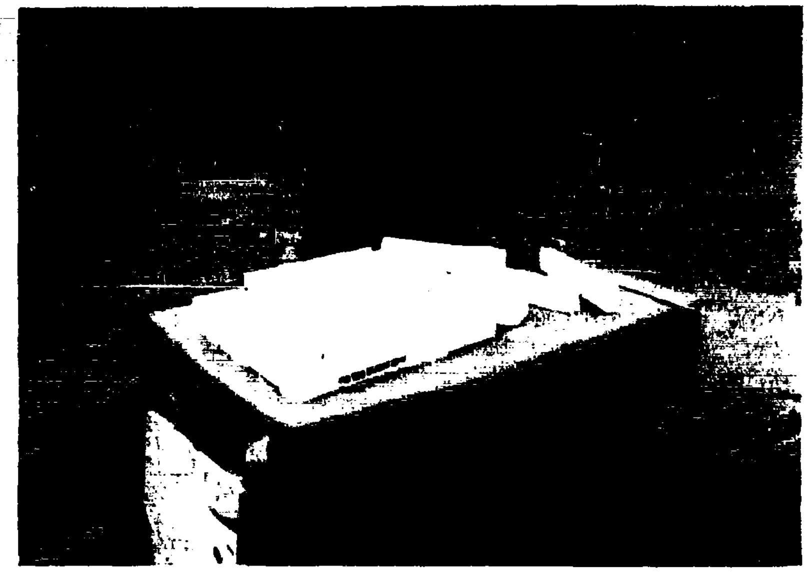
Fig. 7. Pole charge being attached to concrete wall.



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H7618

Fig. 8. Fabrication of pole charge from conventional explosive blocks. This 40-pound charge produced a successful breach.

The 80-pound charge obliterated 13 feet of concrete to a depth of 8 to 10 feet. The quantity of explosive was obviously excessive; therefore, the charge on the succeeding shot was reduced to 50 pounds. This charge, detonated 5 feet under water as was the last, also breached a large section of the wall, toppling the top of the wall into the water. The following charge, which weighed 40 pounds and also was attached 5 feet under water, breached the wall with sufficient strength to break off 4 to 5 feet of the adjoining section of the wall and turn it over into the water behind the wall (Fig. 8).

Since the 40-pound charge successfully breached the wall, the explosive weight was reduced to 30 pounds for the next test. This 16½-inch by 16-inch charge was 2 inches thick and effectively breached the wall (Fig. 9). At this point on the lower guide wall, the water behind the wall was just 5 feet 5 inches deep, even though the water on the channel side was about 20 feet deep. From this point on in the tests, the silt behind the guide wall became an important factor.

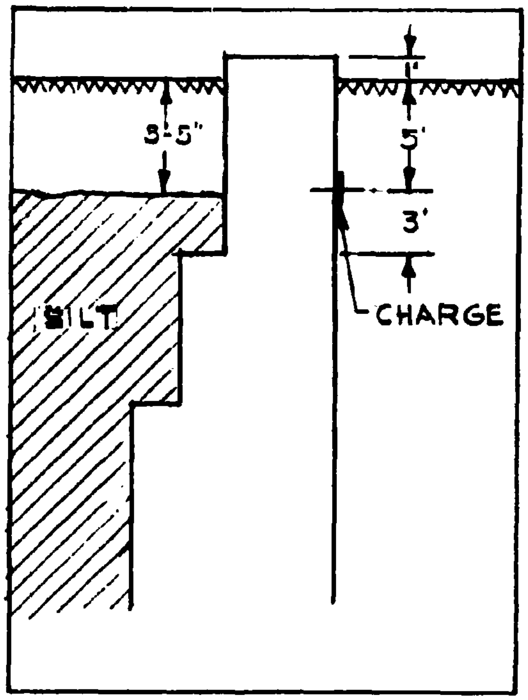

Fig. 9. Cross section of lower guide wall showing silt deposit at point of first 30-pound charge. Charge successfully breached wall.

The next charge was fired at a point where the silt deposit behind the lower guide wall began 4 feet below the water level. The charge was placed 7 feet below the water level; consequently, there was approximat^ly 3 feet of silt above the center of the charge on the opposite side of the wall. The explosive charge was increased in size to 40 pounds in an attempt to compensate for the silt behind the wall (Fig. 10). This charge, a square 16 inches on a side and 3 inches thick, did not breach the 5-foot wall.

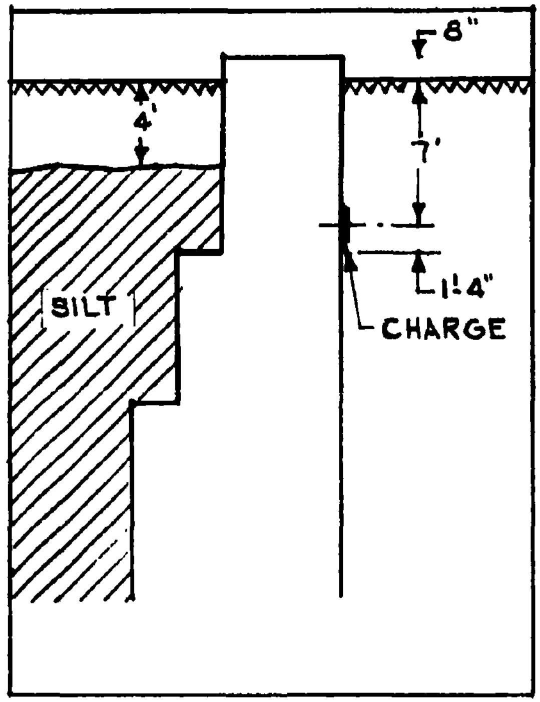

Fig. 10. Forty-pound charge placed 7 feet under water at point where silt deposit behind wall was 4 feet from water surface failed to breach wall.

The 40-pound charge was repeated, this time 5 feet instead of 7 feet under water. The silt was $2\frac{1}{2}$ feet below the surface on the shore side of the pier (Fig. 11). The charge produced a good breach.

Another 40-pound charge was attached to the wall with its center 3 feet 3 inches below the surface. At this time, the water level was 2 feet 9 inches below the top of the concrete; thus,

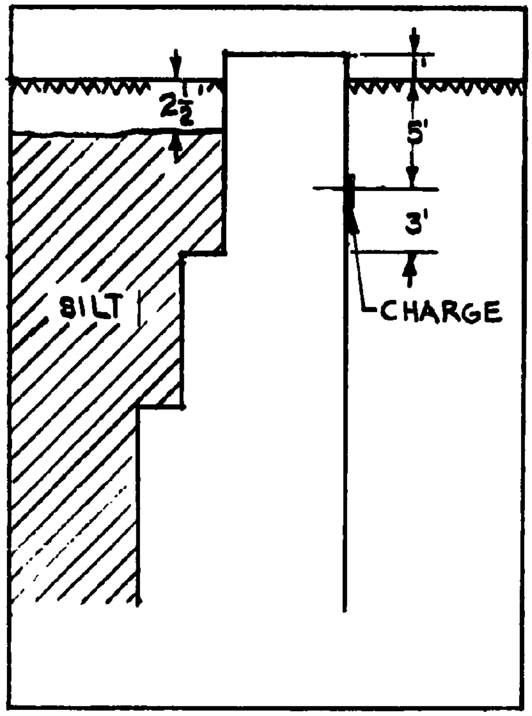

Fig. 11. Forty-pound charge 5 feet under water effectively breached wall.

the charge was a total of 5 feet below the top of the concrete. The water was 2½ feet deep behind the wall. This charge successfully breached the concrete.

Another 40-pound charge 5 feet under water and one 6 feet under water, each with depths of water behind the wall between 4 and 4½ feet, also breached.

A 40-pound charge was then placed attached 7 feet below the surface. The wall thickness changed, at this point, from 5 feet to 7 feet. The water behind the wall was just 2½ feet deep (Fig. 12). Part of the charge was directly behind the step and had to act against 7 feet, instead of 5 feet of concrete. Also, the silt was about 4 feet above the center of the charge, so it is not surprising that it failed to breach.

The next tests were conducted to evaluate further the effect of the water as a tamping factor. A 40-pound charge was

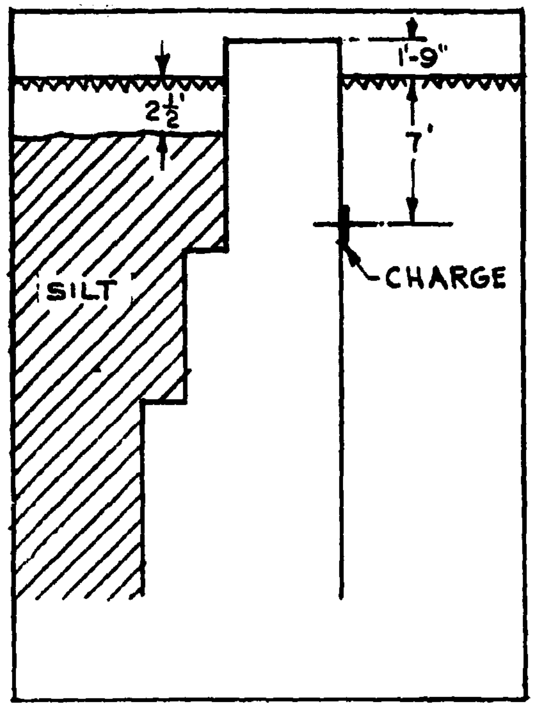

Fig. 12. Forty-pound charge 7 feet under water failed to breach wall. Note that charge was opposite point where wall widened to 7 feet.

placed with its center 2½ feet below the surface of the water. This test was conducted on the upper guide wall of Lock 30 where the water level, at this time, was 5½ feet below the top of the wall. The upper guide wall increased from 5 to 7 feet in thickness 10 feet from the top of the wall; however, the charge was about 1½ feet above the step. This charge failed to breach the wall (Fig. 13). Next, a 50-pound charge was placed 2½ feet below the water level, on the shore side, so that less interference would result from the 7-foot thickness. The 50-pound charge was followed by a 45-pound charge tested in the same manner. Both of these charges breached the wall (Fig. 14).

The next two charges were fired simultaneously to gain some information on the required distance between underwater charges placed on a long structure as well as information on 40-pound charges. Two 40-pound charges were placed on the shore side of the upper guide wall just above the step at which the upper guide

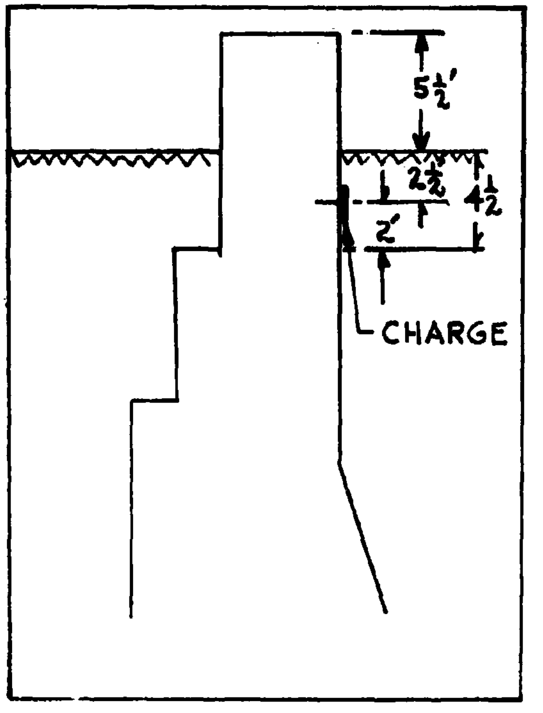

Fig. 13. Cross section of upper guide wall showing 40-pound charge placed on wall 2½ feet below water level. Charge did not effectively breach wall.

wall increased from 5 to 7 feet in thickness and at a depth of 4 feet. The charges, spaced 26 feet apart, were fired by the same technique as that used for a single charge. Each charge was primed with a nonelectric cap at the end of a length of detonating cord. The detonating cord tails were initiated by electric caps wired together in series. The electric caps were fired by a high-voltage pulse from the photographic synchronizer which may have produced a nearly simultaneous detonation of the charges. Two 35-pound charges were fired on the upper guide wall on Lock 29. This was the only portion of Lock 29 that was of value for these tests. The area between the remainder of the guide walls and the bank was filled with earth and debris; consequently, they were not considered to be of value for comparison with previous tests. This unfavorable condition, combined with the urgency of the scheduled river clearance demolition, was the basis for the decision to conclude the research work after these final tests. The tests were both fired with charges placed on the shore side of the wall 4 feet below the surface of the water (Fig. 15).

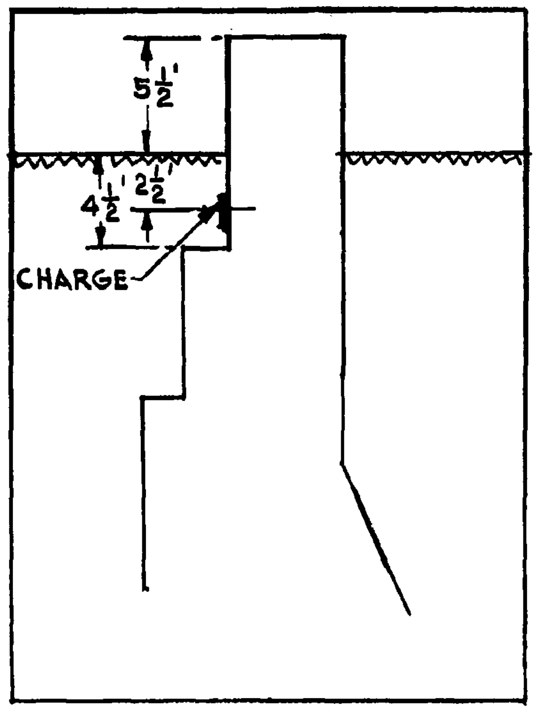

Fig. 14. Forty-five-pound charge placed 2½ feet below surface on shore side of wall effectively breached wall.

b. Results. Results of the tests were briefly described in subparagraph a. Table I is a compilation of results of testing underwater charges. Little additional information was available concerning the results because the water of the Ohio River was murky and the current swift enough to make it difficult for a diver to evaluate the damage. Engineers were able to estimate the damage by making a study of the effect on the surface, by probing the fragments, and by diving down under the water and feeling the damaged material.

The 80-pound underwater charge was obviously excessively large. Thirteen feet of the concrete wall was demolished completely, and another 15 feet of wall was pushed out of place. Engineers probed the area where the 13 feet of wall had been and found that the wall was pulverized to a depth of 8 to 10 feet below the surface of the water (Fig. 16). When the charge weight was reduced to 50 pounds, a smaller section of wall was breached and the concrete toppled over into the water. The following 40-pound charge

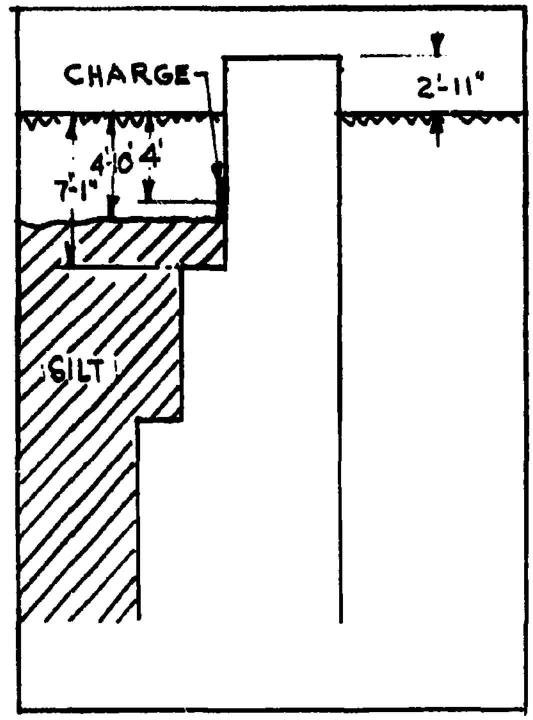

Fig. 15. Upper guide wall of Lock 29 showing location of 35-pound charge placed 4 feet under water. Charge effectively breached wall.

broke off about 10 feet of concrete 4 to 5 feet deep and toppled it back into the water behind the charge (Fig. 17). The next 30-pound charge produced a clean breach but did not topple the wall. The wall was pushed back, however, and a portion of the wall was spalled out from the top rear down as far as could be probed in the silt behind the wall (Fig. 18).

The 40-pound charge placed 7 feet under the water level failed to breach the wall. A diver determined that the crater was about 2 to 2½ feet deep, but the damage on the spall side could not be estimated because of the silt. The water was about 4 feet deep.

The next two charges were 40-pound charges fired 5 feet and 3 feet 3 inches under water, respectively. Both breached. The first charge completely breached a section of wall blowing the top over into the pool behind the wall and crumbling the concrete

Table I. Summary of Results of Underwater Charges

Explosive Weight (lb)	Depth of Water above Charge (ft)	Depth of Water above Silt Deposit (ft)	Thickness of Wall behind Charge (ft)	Breach
80	5	*	5	Yes
50	5	*	5	Yes
40	5	*	5	Yes
30	5	5-1/2	5	Yes
40	7	4	5**	No
40	5	2-1/2	5	Yes
40	3-1/4	2-1/2	5	Yes
40	5	4-1/2	5	Yes
40	6	4-1/2	5	Yes
40	7	2-1/2	7	No
40	2-1/2	*	5	Yes
50	2-1/2	*	5	Yes
45	2-1/2	*	5	Yes
40	4	*	5	Yes
40	4	*	5	Yes
35	4	*	5	Yes
35	4	*	5	Yes

* Depth great enough not to affect results.

** Wall widened to 7-foot thickness 8 inches below charge.

down 6 or 7 feet. Ten feet of wall was pushed back out of line with the remainder of the wall. The second charge pushed out of line a section about 10 feet long ending at a construction joint. A section next to the breached area was broken off and blown over on one side (Fig. 19).

The next three charges, which weighed 40 pounds each, were fired at depths of 5 feet, 6 feet, and 7 feet under water. The charge fired 5 feet under water completely breached the wall. A large section of wall was broken free at a construction joint and shoved out of line. The charge fired at a depth of 6 feet completely breached the wall, but with less damage than in the previous shot. Four to five feet of the top of the wall on both sides of the charge were broken off and toppled back. The crater produced was probed, and the concrete seemed to be completely pulverized. The 40-pound charge, fired at a depth of 7 feet, did not breach. A large vertical crack was produced which went entirely through the concrete but extended down for only 3 feet. A large horizontal crack was

H7647

Fig. 16. Detonation of 80-pound underwater charge.

H7628

Fig. 17. Concrete toppled back into water by 40-pound charge placed 5 feet under water.

H7694

Fig. 18. Results of 30-pound charge which had been placed 5 feet under water. Wall was breached at point where charge was placed.

H7704

Fig. 19. Remains of wall breached by 40-pound charge placed 3 feet 3 inches under water.

produced about 4 feet from the top of the wall. A diver found that the crater was only $1\frac{1}{2}$ to 2 feet deep.

A 40-pound charge, placed $2\frac{1}{2}$ feet under water, did not completely breach the wall. The wall was nearly breached, however. The crater on one side was about 10 inches deep and $2\frac{1}{2}$ feet in diameter, and the spall was 3 feet 2 inches deep at the deepest point and extended over approximately 6 feet. The spall was primarily above the waterline.

When the 50-pound charge was fired $2\frac{1}{2}$ feet under water, an effective breach was produced. The crater extended about $2\frac{1}{2}$ feet above the waterline and about 20 feet along the wall. The crater seemed to extend about 3 feet below the water level. The spall dimensions were about 8 feet by 8 feet (Fig. 20).

The 45-pound charge fired $2\frac{1}{2}$ feet under water produced a good breach, but the spall and the crater were somewhat smaller than the previous shot (Fig. 21).

The two 40-pound charges, spaced 26 feet apart and fired at approximately the same time, produced a continuous breach 36 feet long. Damage continued beyond the full breach for another 10 feet at each end. The height of the breach appeared to be about 5 feet (Fig. 22).

The two 35-pound charges fired 4 feet under water on the upper guide wall of Lock 29 produced roughly equivalent damage. Fifteen-foot sections of concrete were completely removed from the wall. These sections were broken free at vertical construction joints. The concrete did not appear to be of good quality; some form-lumber was even found embedded in the concrete about 4 feet from the top.

8. Underwater Opposed Charges.

a. Procedure. The opposed charge technique, already disproved above water, was next tested under water. Two 20-pound charges were formed in slabs 14 inches on the side and 2 inches thick (Fig. 23). The charges were placed on the upper guide wall of Lock 30. The water level was $5\frac{1}{2}$ feet below the top of the concrete. The charges were fired with a detonating cord bridle carefully measured to insure that the legs of the bridle were of equal lengths. The blasting caps were inserted in the explosive on the side of the charge next to the concrete wall (Fig. 24). (The distortion in the explosive caused by detonation of the detonating cord across the explosive would occur too late to affect the charge detonation.)

H7685

H7687

Fig. 20. Crater produced by 50-pound charge fired $2\frac{1}{2}$ feet under water (top) and spall produced by same charge (bottom).

H7686

H7688

Fig. 21. Crater produced by 45-pound charge fired 2½ feet under water (top) and spall produced by same charge (bottom).

H7701

H7698

Fig. 22. Crater produced by two 40-pound charges placed 4 feet under water, 26 feet apart, and fired at approximately same instant (top); and spall produced by same two charges (bottom).

H7621

Fig. 23. Two 20-pound pole charges prepared as opposed charges for underwater demolition.

H7658

Fig. 24. Underwater opposed charges prepared for simultaneous detonation.

When the previously described charges failed to breach the concrete, two more charges were made up with charges 4 inches thick and with caps placed in the charge on the face away from the concrete. (This change of procedure was in accordance with the recommendations of Special Forces personnel who were observing the tests.) The charges were $2\frac{1}{2}$ feet under water. The surface of the water was $5\frac{1}{2}$ feet below the top of the concrete.

b. Results. The two opposed 20-pound charges, which were made 2 inches thick and were detonated with caps on the face next to the concrete (Fig. 25), produced two small craters. The craters were about 2 feet in diameter and 8 inches deep. There was extensive spall above each crater starting at the waterline and going up about 1 foot. The craters produced by the 4-inch-thick charges were about 10 inches deep, but the diameters of the craters were just 16 inches. Spalling was again produced above the waterline on each face.

H7636

Fig. 25. Simultaneous detonation of two 20-pound opposed charges fired under water.

III. DISCUSSION

9. Examination of Methods of Testing. There was reason to question the quality of the concrete in the Ohio River locks. The concrete, poured in 1919, contained unwashed river sand and aggregate. Since the test structures had been constructed, the concrete had been damaged repeatedly, capped, and repaired at various times. In addition to this difficulty, the varying levels of silt which had accumulated behind the walls presented a variable that was difficult to control. The construction joints in the walls also added somewhat to the confusion in analyzing the results.

An attempt was made to estimate the compressive strength of the concrete by use of a Schmidt concrete testing hammer. These tests had to be made on relatively new concrete rather than on the concrete that was actually tested because the walls had all been capped. Even on this concrete, the estimates from the Schmidt Impact Hammer readings were biased by exposed aggregate which had generally been weathered until it interfered with the readings of the hammer; consequently, the readings were not considered in the analyses here.

During the tests of charges fired above the water level, some energy was undoubtedly lost because the charges were placed just 2 inches above the water. Thus, although no advantage was gained from the tamping effect of the water, energy was lost on the opposite side of the wall as a consequence of the water interface around the lower half of the area affected by the spall. If the charges had been placed higher, however, energy would have been lost through the top of the wall. Hence, conclusions formed from the results of tests of explosive placed close to the waterline are considered conservative because the explosive was operating at a disadvantage.

The effects of the underwater charges were confused with the counter effects produced by the accumulation of varying levels of silt behind the walls. More definitive results would have been obtained if this silt had been dredged from behind the walls in the vicinity of the shots. This might have been accomplished; however, with the limited time available and shortage of personnel and equipment, it was considered impracticable. As a result, failure of at least one of the 30-pound charges could be attributed to either excess of silt accumulation or to an inadequate charge. For the same reasons, the effect of varying the depth of water above the charge could not be fully evaluated. Nevertheless, the information obtained will be valuable for designing future underwater tests.

The technique of placing explosive against the wall under water was effective but would be difficult under adverse weather conditions. The stud gun frequently failed to fire because of improper positioning against the rough, water-eroded surface of the concrete; and the studs would often break off or fail to penetrate when they hit hard pieces of aggregate in the concrete. Testmen found it was difficult to force the stud gun into proper contact with the concrete because they were not able to apply sufficient force from the boat or from the water to overcome the tension of the spring in the stud gun. One of the guns was fitted with an underwater cocking device which was some help. Some of the failures of the stud guns to operate effectively in these tests could be attributed to fouling caused by sand and silt suspended in the water.

Care was taken to insure that the opposed charge tests were conducted in such a way as to insure simultaneous detonation of charges placed exactly opposite one another. Personnel from Special Forces, who had experience with use of opposed charges against small structures and who advocated their use for longer structures, were present during the two underwater opposed charge tests. The Special Forces personnel inspected the techniques employed and stated that similar methods had been used by them.

10. Analyses of Test Results. One of the external 50-pound charge tests fired above water produced an excellent breach, but the other did not. The only difference between the two tests, as far as test engineers could determine, was that the second charge was made more compact by elimination of the ends of the plastic covers on the base layer. The difference in the results was probably caused by the normal variation observed in demolition testing. Because the second charge had nearly breached the wall, it was estimated that a 60-pound charge would be effective. This estimate is undoubtedly a safe one because some of the destructive energy was lost as a result of the placement of the charge close to the water level.

For underwater charges, one 30-pound charge 5 feet under the surface and two 35-pound charges 4 feet under the surface effectively breached the 5-foot concrete walls. However, two 40-pound charges 7 feet under water and one 40-pound charge 2½ feet under water failed to breach. The 40-pound charge 2½ feet under water probably failed because there was inadequate water above the charge to tamp it effectively. In one of the other failures, the charge was placed opposite the step at which the wall increased in thickness from 5 to 7 feet. Also, there was about 4½ feet of river silt above the charge on the opposite side of the wall. In the other failure, the charge was placed just barely above the step and, in addition, there was about 3 feet of silt above the charge on the opposite side of the wall. Six other 40-pound charges fired at depths of 4 to 6 feet and against as much as $2\frac{1}{2}$ feet of silt were successful. From these results, it is believed safe to conclude that a 40-pound charge placed 5 feet under water is adequate to breach a nonreinforced, 5-foot thick concrete wall when there is no silt on the opposite side.

Both the above-water and below-water opposed charge tests seem to repudiate conclusively the value of opposed charges for demolition of piers or other long concrete structures. The recommended procedure calls for use of 10 pounds of explosive, placed half on each side for demolition of a 5-foot pier. In the tests on the Ohio River, 40-pound charges, four times the weight recommended, were divided, with half placed on each side of the 5-foot wall. These walls were not reinforced and were constructed of only moderately good concrete, and yet the large opposed charges were found to no more than dent the surface of the concrete. Even if the procedure is theoretically capable of demolishing the piers, it seems evident that if professional demolition technicians could not achieve results, there is little likelihood that the procedure would be practicable for troops in the field.

11. Evaluation of Tested Techniques. Although further experiments should be conducted on underwater demolition, especially against reinforced concrete, it seems reasonably certain that underwater charges will require at least 30 percent less explosive than above-water charges to achieve the same result. Consequently, techniques for attaching underwater charges should be given thorough testing. The use of the pole charge is one technique which may prove to be effective. The pole charges can be made up in segments in rear areas and carried to the target. Procedures for placement of the pole charges should be refined, and an alternate technique for attaching charges should be developed. Use of the explosive-actuated stud gun has potential, but requires testing on various types of piers to insure that it will be effective. Improvement of the stud gun may be possible to make it more reliable, especially for underwater use.

In view of the significant amount of explosive which can be saved by underwater demolition of concrete piers, it seems especially important to conduct underwater tests on various sizes and types of piers as well as to develop methods of attachment of charges.

IV. CONCLUSIONS

12. Conclusions. It is concluded that:

a. Sixty pounds of Composition C-4 formed in a roughly square-shaped charge, 3 inches thick, is required to breach a nonreinforced concrete structure when the explosive is attached above the waterline, and 40 pounds, 3 inches thick, when the explosive is attached at a point 5 feet or more under water.

b. The opposed charge technique for demolition of concrete is not effective against long concrete structures.

c. Techniques for attaching explosive to massive concrete targets under water should be developed and tested.

d. Tests are required to establish optimum sizes and shapes of explosive charges for underwater demolition of massive concrete structures.

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APPENDIX

AUTHORITY

Item No. 3077
CETC Mtg # 312

R & D PROJECT CARD	TYPE OF REPORT: New	REPORT CONTROL SYMBOL: CSCRD-1(R1)

1. PROJECT TITLE: DEMOLITIONS	2. SECURITY OF PROJECT: Unclassified	3. PROJECT NO.: 8FC7-10-002
	4. INDEX NUMBER: —	5. REPORT DATE: 1 Feb 1960
6. BASIC FIELD OR SUBJECT: Mines and Obstacles	7. SUBFIELD OR SUBJECT SUB GROUP: Fortifications, Obstacles & Demolitions	7A. TECH. OBJ.: LC-13
8. COGNIZANT AGENCY: Corps of Engineers	12. CONTRACTOR AND/OR LABORATORY: USA Engr. Res. & Dev. Labs., Ft. Belvoir, Va.	CONTRACT/W. O. NO.
9. DIRECTING AGENCY: Res. & Dev. Div., OCE		
10. REQUESTING AGENCY: Office, Chief of Engineers		

11. PARTICIPATION AND/OR COORDINATION	13. RELATED PROJECTS	17. EST. COMPLETION DATES
		RES. Cont.
		DEV. Cont.
		TEST Cont.
		OP. EVAL. Cont.
	14. DA. & APPROVED: 4 March 1960 by GSUSA	
	15. PRIORITY: 1-A / 16. MAJOR CATEGORY	

18. FIS. YR.	FISCAL ESTIMATES
60	3 M
61	4. M
62	33 M
Est. Rate P/A	35 M

19. REPLACED PROJECT CARD AND PROJECT STATUS: This project supersedes part of Project No. 8-07-10-000, 31 December 1959.

20. REQUIREMENT AND/OR JUSTIFICATION - There is a continuing requirement for development of new or improved equipment in the field of demolitions.

Justification for the development of each piece of equipment, with appropriate CDOG references, is included in the Task Cards as listed in paragraph 21c below.

21. BRIEF OF PROJECT AND OBJECTIVE

a. Brief:

(1) Objective:

(a) To provide for the conduct of the research and development necessary to supply required equipment to the Army, and to the other Departments as may be required and authorized, in the field of demolitions.

(b) The security classification of the individual tasks of this project will be in accordance with their content.

(2) Military Characteristics: The Military Characteristics for each item being developed are included as Exhibits "A" to each of the Task Cards as listed in paragraph 21c below.

22. CASE (R & D)	SN.	CN.	C.	E.	I.	A.

DD FORM 613, 1 APR 55 — REPLACES DD FORM 613, 1 JAN 52. PAGE 1 OF 2 PAGES

Item No. 3077
CETC Mtg. # 31

RAD PROJECT CARD
CONTINUATION SHEET

1. PROJECT TITLE	2. SECURITY OF PROJECT	3. PROJECT NO.
DEMOLITIONS	Unclassified	8F07-10-002
	4. ——	5. REPORT DATE 1 Feb 1960

b. Approach: The approach to each task is set forth in the Task Cards as listed in paragraph 21c below.

c. Tasks: This project is composed of the tasks as listed herein. The completion of tasks and the establishment of new tasks will be recorded by the revision of this paragraph.

(1) Item No. 3054, Task No. 8F07-10-002-01, Engineering Studies & Investigations, Demolitions.

(2) Item No. 1357, Task No. 8F07-10-002-02, Demolition Material & Equipment (Suspended).

d. Other Information:

(1) Scientific Research: None

(2) References: None

Category 13 - Mine Warfare and Demolitions

DISTRIBUTION FOR USAERDL REPORT 1730-TR

TITLE Demolition of Concrete Locks on the Ohio River (Research Phase)

DATE OF REPORT 20 Nov 62 PROJECT 8F07-10-002 CLASSIFICATION Uncl.

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The Engineer School Library Building 270 Fort Belvoir, Virginia	1	-
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Director, Unconventional Warfare Dept Army Special Warfare School Fort Bragg, North Carolina	2	-

ADDRESSEE	REPORT	ABSTRACT
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Director, Marine Corps Development Center Marine Corps Landing Force Development Center Marine Corps Schools Quantico, Virginia	1	-
President, Marine Corps Equipment Board Marine Corps Schools Quantico, Virginia	1	-
Others		
Dr. Wilbur Duval Bureau of Mines College Park Research Center College Park, Maryland	1	-

AD ______ Accession No. ______
U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia - DEMOLITION OF CONCRETE LOCKS ON THE OHIO RIVER (RESEARCH PHASE) - Howard J. Vandersluis

Report 1730-TR, 20 Nov 62, 34 pp, 25 illus, 1 table
DA Proj 8F07-10-002 Unclassified Report

This report covers tests of demolition techniques against massive nonreinforced concrete walls. Charges detonated on concrete above water were compared with similar charges detonated under water. An opposed charge technique was also tested. Tests conducted above water indicated that nonreinforced, low-quality concrete can be demolished with 30 percent less explosive (in a conventional package) than can reinforced, high-quality concrete. Underwater demolition required 30 percent less explosive than did demolition above water. Conclusions: (a) Sixty pounds of Composition C-4 formed in a roughly square-shaped charge, 3 inches thick, is required to breach a nonreinforced concrete structure when the explosive is attached above the waterline, and 40 pounds, 3 inches thick, when the explosive is attached at a point 5 feet or more under water. (b) Opposed charge technique for demolition of concrete is not effective against long concrete structures. (c) Techniques for attaching explosive to massive concrete targets under water require thorough testing. (d) Tests are required to establish optimum sizes and shapes of explosive charges for underwater demolition of massive concrete structures.

UNCLASSIFIED

1. Mines and Obstacles - Fortifications, Obstacles, and Demolitions
2. Contract - None

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